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A RECENT IMPROVEMENT IN THE NAVY'S NUMERICAL-STATISTICAL SCHEME FOR FORECASTING THE MOTION OF HURRICANES AND TYPHOONS

by

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ABSTRACT:

The Navy's numerical-statistical scheme for forecasting the motion of tropical cyclones is reviewed. The numerical component (HATRACK) represents geostrophic steering of the cyclone by the Fleet Numerical Weather Central's smoothed isobaric height fields at 1000, 700, and 500 mb. The statistical component refers to the correction for bias in the numerical steering. The paper introduces an improvement in application of the statistical correction for bias. The enhanced scheme, MODIFIED HATRACK, is applied to forecasts of all named North Atlantic tropical cyclones in 1967 and 1968 and to a select number of 1967 North Pacific tropical storms and typhoons. The accuracy of MODIFIED HATRACK is found to excel the official forecast and that of the National Hurricane Center's NHC-67 technique for all forecast intervals through 48 hours. MODIFIED HATRACK errors range from an average of 40 nautical miles at 12 hours to 240 nautical miles at 48 hours. Such figures represent a 60 percent and a 10 percent reduction in errors, respectively, compared to official forecasts in the Atlantic. For the Pacific, the error reductions are of the order of 15 percent.

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1. Introduction

A numerical-statistical scheme for forecasting the motion of tropical cyclones has been under development at the Naval Postgraduate School and Fleet Numerical Weather Central (FNWC), Monterey, California, since 1965. Details are available in recently published literature and reports to the meteorological community (Renard, 1968 and 1969; Renard and Levings, 1969).

In order to facilitate the explanation of a recent improvement to the scheme, a brief review of the numerical component of the forecast procedure follows. The tropical cyclone center is steered in three-hour time steps with geostrophic winds derived from heavily-smoothed isobaric height analyses and/or prognoses which are identified as SR fields by FNWC (Hughes, 1967). The numerical steering forecasts derived from the SR product are widely known as HATRACK (Hurricane and Typhoon Tracking) forecasts. Presently, such forecasts are generated in operational real time for North Pacific and Atlantic tropical cyclones by FNWC or pertinent Navy Weather Centrals. The forecast interval is six hours, usually extending to 72 hours, with forecasts computed separately from the 1000, 700, and 500 mb SR fields.

These advisories on movement of tropical cyclones are used as objective guidance material in preparing the official forecast[1]. In general, the SR 700 mb HATRACK estimates of the zonal motion of the cyclone are more accurate than their counterparts computed from the 1000 and 500 mb surfaces. The steering level of best performance for the meridional component of the forecast appears to be a function of storm structure and area of occurrence.

Evaluations have shown that the HATRACK forecasts are competitive with the official forecasts. Specifically, the numerically forecasted direction of cyclone motion is acceptable but the speed is too slow. Such a result may be viewed as a bias in the vector motion forecasted by the HATRACK program. Several statistical schemes for correcting this bias have been proposed and tested with the conclusion that it is operationally feasible and worthwhile to modify the HATRACK forecast by empirical methods.

It is the purpose of this report to introduce a much-improved method of objectively correcting for the bias of the HATRACK forecast and to present evaluations of the modification scheme for 1967 and 1968 Atlantic and Pacific tropical cyclone data. A procedure for correcting the HATRACK bias, as reported by Renard and Levings (1969), is considered to be less effectual than the technique described in the following paragraphs. The HATRACK forecast, coupled with a statistical modification executed in the way described here, is given the descriptive title of MODIFIED HATRACK forecast.

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[1]The official forecast represents the documentary forecast issued by the civilian and/or military weather central; it is disseminated to civilian and/or military users by press, radio, television, etc.

2. Statistical Modification of the HATRACK Forecast

The modified HATRACK scheme is illustrated by a typical forecast for a hypothetical North Atlantic hurricane. A section of a HATRACK forecast set[2] (Table I) is used to generate the MODIFIED HATRACK values.

With reference to Table I, six and twelve-hour forecasts are made from the known hurricane position at 25.0N, 65.0W at 0000 GMT, day 1. It is presumed that the cyclone's verifying positions are known with an acceptable degree of accuracy shortly after 0600 and 1200 GMT. Thus, from the forecast and observed cyclone positions, errors may be computed. The HATRACK error is defined as verifying position minus HATRACK position. A corresponding relative HATRACK error is defined as the ratio of the HATRACK errors for Δt and 12 hours (i.e., error for an interval Δt hours/error for an interval of 12 hours).

Using the forecast and verifying information in Table I, the modification scheme may be described as the linear extrapolation of the known HATRACK errors at short-period intervals, such as 6 and 12 hours, to forecasts for the longer-period intervals of 18 to 72 hours in the same set. The application is carried out separately for the latitude and longitude components of the HATRACK forecasts with certain empirical restrictions.

The diagram in Fig. 1 may be employed to obtain the MODIFIED HATRACK forecast. The ordinate is relative HATRACK error while the abscissa is HATRACK

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[2] A HATRACK forecast set includes only those HATRACK forecasts generated from a single known cyclone position. Such positions are determined from estimation or observation by radar, aircraft reconnaissance, etc.

forecast interval. Known relative HATRACK error information is plotted in the clear section of the diagram; the derived forecast relative HATRACK error curve appears only in the blocked section. From Table 1, the relative latitude and longitude HATRACK errors are plotted on Fig. 1 as 0.7, 1 (-Δ-) and 1.5, 1 (-0-), respectively, at the six and twelve hour intervals, with the connecting lines extended linearly into the blocked section of the diagram. It is the linearly extrapolated curves which generate modifications to the HATRACK forecasts.

Table 2 is a repeat of Table 1 with the addition of HATRACK error information derived from the curves in Fig. 1. For example, the 18-hour HATRACK positions of 25.9N, 65.6W may be modified. The forecast relative HATRACK error at 1800 GMT, day 1, is +1.3 for latitude and +0.5 for longitude, yielding a forecast bias in the HATRACK position of +1.3 deg lat and +0.1 deg long (i.e., the forecast HATRACK error for interval Δt = forecast relative HATRACK error at Δt x HATRACK error for 12 hours). Thus, the MODIFIED HATRACK forecast for 1800 GMT, day 1, is 27.2N, 65.7W (i.e., the MODIFIED HATRACK position = HATRACK position plus the forecast HATRACK error). Since the 1800 GMT day 1 forecast is determined from the 1200 GMT, day 1 data, the MODIFIED forecast interval is regenerated as six hours. The remainder of Table 2 illustrates the MODIFIED HATRACK forecasts for several other intervals of the forecast set.

Since, empirically, the linear relative error curves are restricted to lie within the blocked area, the six-hour relative HATRACK error may range only from +0.5 to +2.0. Values of six-hour relative HATRACK errors greater than +2.0 (less than

+0.5) should be plotted at +2.0 (+0.5). These restrictions on slope of the relative error curve, and, in addition, the maximum allowable value of three units of relative HATRACK error, enhances the accuracy of the modification scheme. It is to be noted from Fig. 1 that for the commonly occurring case of HATRACK errors increasing with time in the first 12 hours of the forecast set (e.g., latitude curve), the algebraic sign of the forecast relative HATRACK error does not change with time. However, for the less frequent case of the HATRACK error decreasing with time up to 12 hours (e.g., longitude curve), the algebraic sign of the relative HATRACK error will change for six-hour relative HATRACK errors in excess of +1.1. The forecast relative HATRACK error first become negative at intervals > 72 (> 18) hours for a six-hour value of +1.1 (+2.0), with the relation linear in the intervening intervals. Further, for the typical HATRACK forecast set of 72 hours, the MODIFIED forecast interval is limited to 60 hours, since the regenerated interval is counted from the verifying time of the 12-hour HATRACK forecast.

The abscissa in Fig. 1 may be relabeled to accommodate HATRACK forecasts initiated from times not divisible by six. As an example, for the North Atlantic warning times of 0400, 1000, 1600, and 2200 GMT, the eight and fourteen hour HATRACK forecasts should be used to generate the forecast relative HATRACK error curves. In this case, increase scale values by two hours and proceed as indicated above. It is advisable not to use HATRACK errors for forecast intervals less than six hours since errors in locating the cyclone are quite deleterious to these very short-period forecasts.

The next section represents an extensive evaluation of the MODIFIED HATRACK forecasts in relation to HATRACK and official forecasts.

3. Evaluation of HATRACK, MODIFIED HATRACK and Official Forecasts

A. Atlantic: 1967 and 1968

(1) HATRACK Forecasts

Tables 3 and 4 show evaluations of the available operational HATRACK forecasts for all named North Atlantic tropical cyclones in 1967 and 1968. All forecasts were made from SR 700 mb information only. Statistics for both Anal- and Prog-mode HATRACK forecasts are combined in the tables. Prog-mode indicates that SR prognostic fields at six-hour intervals were used to generate the HATRACK forecast, while the Anal-mode employes only the single SR analysis closest in time to that of the cyclone's known position. See Renard and Levings (1969) for details. In 1967, 71 percent of the forecasts were Prog-mode while in 1968, 64 percent were of that type.

The error statistics are given in nautical miles per hour of forecast interval for the latitude, longitude, and total vector motion of the storm. In addition, the HATRACK errors are compared to the official forecast errors (OFF) as published by Fleet Weather Facility, Jacksonville, Florida (Fleet Weather Facility, 1968 and 1969). The data are presented as non-homogeneous and homogeneous samples; the former includes all HATRACK and official forecast errors, regardless of initiation or verification time, while the homogeneous set considers only those HATRACK and official forecasts begun and verified at the same clock hour. As a slight exception, the forecasts in the homogeneous sample of 1968 verify at the same time but are not initiated at the same time.

The following discussion serves as an example to aid in interpreting the tabular data. Consider the non-homogeneous sample first. The forecast statistics are collected by grouped intervals to simplify the presentation and focus the results. In 1968 (Table 4) there are 186 HATRACK (N) and 106 official (0) forecasts for the intervals 7, 8, 9, --- 16, 17, 18 hours. Only eight-hour official forecasts exist in this grouped interval. The average latitudinal (longitudinal) error of the HATRACK forecasts is 5.4 (4.1) kt while the average magnitude of the total vector error is 7.5 kt. The corresponding ratios of official to HATRACK errors (OFF/HATR) are .83 (1.37) and 1.09. A ratio in excess of one indicates that the average official errors exceed those of HATRACK.

Interpretation of the homogeneous sample is similar except that the HATRACK forecast intervals are limited to the discrete hours of 12, 24, 48, and 72, as the closest match to the official forecast intervals of 8, 20, 44, and 68 hours.[3] The quasi-homogeneity of the table is due to the fact that the standard official warning times in 1968 were 0400, 1000, 1600, and 2200 GMT, while the HATRACK forecasts corresponding to these were issued at 0000, 0600, 1200, and 1800 GMT, respectively. Thus, the 8-hour official and 12-hour HATRACK forecasts verify at the same time, while the latter is issued four hours before the official.

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[3]The 8, 20, 44, and 68 hour intervals are generally referred to as the 12, 24, 48, and 72 hour forecasts (Fleet Weather Facility, 1968 and 1969).

Average error statistics in Tables 3 and 4 may be interpreted to indicate the following with regard to the operational HATRACK forecasts.

(i) Forecast error per hour decreases with increasing forecast interval.

(ii) The latitudinal (longitudinal) component of the error is relatively greatest for the short-period (long-period) forecast intervals.

(iii) Considering all forecast intervals, HATRACK forecasts are less (more) accurate than the official in the meridional or latitude (zonal or longitude) component of the storm's motion. This is shown by the average error ratio. In terms of the total error, HATRACK slightly excels the accuracy of official forecasts.

(iv) Comparing the relative accuracy of HATRACK and official forecasts for each of the non-homogeneous grouped or discrete homogeneous intervals indicates there is a tendency for HATRACK to be best for the longest-period interval (i.e., 55-72 hours) while official is most accurate for the 20-hour period.

The homogeneous sample indicates results similar to the non-homogeneous sample. Any differences are due to the dissimilarity of percentage occurrences of the number of cases of each cyclone in the two samples.

Table 5 shows some pertinent relations of the 1967 and 1968 samples as to the geographical area, and the track and stage of the cyclones forecasted by the HATRACK scheme. Perhaps of greatest significance is that most 1967 forecasts were for hurricanes before-recurvature while the 1968 cases were predominantly depression and storm stage types after recurvature. These percentages may relate to the fact that SR 500 mb generated HATRACK latitude steering components nearly as accurate as those from SR 700 mb in 1967 while this was true of SR 1000 mb in 1968.

The area occurrence of HATRACK forecasts shown in Table 5 is less obviously significant. There were more forecasts for storms in area A (i.e., approximately east of 62E) than in B (i.e., approximately west of 62W, south of 30N) and C (i.e., approximately west of 62W, north of 30N) combined in 1967. The 1968 geographical distribution is more uniform. It is to be noted that before-recurvature tracks are usually at the lower latitudes in area A or in the eastern section of area B while after-recurvature positions occur in the eastern section of C and in the northern part of area A.

(2) MODIFIED HATRACK Forecasts

The 1967 and 1968 HATRACK forecasts were corrected for bias in the manner described in Section 2. Best-track positions, determined by FWF Jacksonville, Florida, from post-season analysis, were used as verifying positions for the purpose of determining six- and twelve-hour HATRACK errors (Table 1). A homogeneous set of forecast statistics was derived to compare official and MODIFIED HATRACK forecasts for 1967 and 1968 (Table 6). For all cases, the 8, 20, and 44 hour official forecasts were compared to 12, 24, and 48 hour MODIFIED HATRACK forecasts verifying at the same time. MODIFIED HATRACK forecasts for 72-hours are non-existent.

The results in Table 6 indicate the following:

(i) The MODIFIED HATRACK forecast accuray definitely excels that of official since all error ratios exceed one, except 1968 48-hour longitude forecasts.

(ii) The short-period HATRACK forecasts are improved the most by the correction for bias. This is shown from a comparison of corresponding intervals of the

HATRACK homogeneous samples in Tables 3, 4, and 6. In 1968, the HATRACK latitude error was reduced by 73% due to the modification (from 5.4 to 2.0 kt) and, in 1967, by 58% (from 5.3 to 2.2 kt).

(iii) The error trend of the MODIFIED HATRACK forecasts indicates diminishing advantage of the bias correction with increasing interval.

(iv) There is uniformity in the major results for both years tested giving further strength to the merit of the modification scheme.

(3) MODIFIED HATRACK versus NHC-67 Forecasts

The National Hurricane Research Center, (NHRC), Miami, Florida, has developed a successful statistical approach to forecasting tropical storm motion, known as the NHC-67 technique (Tracy, 1966). Operational 1967 and 1968 NHC-67 forecasts, made in real time, were compared to the MODIFIED HATRACK forecasts. Results are shown in Table 7 for a homogeneous sample. In short, MODIFIED HATRACK excels NHC-67 at all of the intervals evaluated, particularly the 12- and 48-hour intervals.

B. Pacific: 1967

Fifteen 1967 North Pacific tropical cyclones (Opal through Harriet, 30 August to 24 November) were processed similarly to the Atlantic data. Table 8 displays the MODIFIED HATRACK forecast statistics for a sample which is homogeneous with the HATRACK forecasts. For the Pacific, the latitude forecasts are best using SR 500 mb while longitude is best using SR 700. The total error is the vector combination of components from the two steering levels. Also, the sample is for Prog-mode forecasts only, which represents the most accurate of the operational HATRACK forecasts available in 1967. The predominance of error ratios greater than 1 indicates the excellence of the MODIFIED HATRACK forecasts.

Table 9 relates the available 24 and 48 hour official and MODIFIED HATRACK forecasts. 12-hour official forecasts and 72-hour MODIFIED HATRACK forecasts do not exist. It is clear from Tables 8 and 9 that results are similar to the Atlantic, with the MODIFIED HATRACK excelling both the HATRACK and official forecasts. Again, the relative accuracy of MODIFIED HATRACK forecasts decreases with increasing forecast interval.

4. Concluding Remarks

The foregoing discussion represents updated research on forecasting the motion of tropical cyclones (depressions, storms, hurricanes and typhoons), using the Navy's numerical-statistical approach. Results to date suggest that the MODIFIED HATRACK scheme, utilizing steering components derived from FNWC's SR 700 mb (500 mb for latitude, 700 mb for longitude) fields for the North Atlantic (Northwest Pacific), excels the accuracy of the official forecasts. Moreover the computer-oriented approach is completely objective as well as feasible for real-time weather-central operations.

Refinements to the HATRACK MODIFICATION are presently being researched. The goal is to increase the flexibility and utility of the relative error curves as a function of storm track, stage, and geographical area. As data increases over the ocean areas spawning the severe tropical cyclones, due to satellite input, so will the numerical HATRACK forecasts become more accurate. A similar comment is true due to the advances in numerical prognostic modeling. Therefore, the correction for bias in the numerical steering component may be expected to diminish in relative importance in the future.

Until such time as the full impact of data increase and model improvement is evident, it does not appear worthwhile to stratify the bias correction according to cause. Whatever the source, some bias will always exist in the scheme proposed for the following reasons. The cyclone's effective steering level is not a fixed entity even over the period of a forecast set. Moreover, the geostrophic steer, used in the HATRACK program, is only an approximation to the true steering wind even if the level for steering were correctly chosen. Further, there is error in locating the cyclone center, hence error in warning-time and verifying positions. In real time, the former is the more serious error, although the initial-position error decreases proportionately with increasing forecast interval.

It appears unlikely that the desired cyclone forecast accuracy (American Meteorological Society, 1963) of 50 miles in 24 hours (approximately 2 kts) will be achieved in the foreseeable future. On the other hand, there is little question that proper and timely operational use of the subject numerical-statistical scheme will enhance the accuracy of the official forecast. Such an approach may be regarded as an example of the man-machine mix of forecasting atmospheric phenomena.

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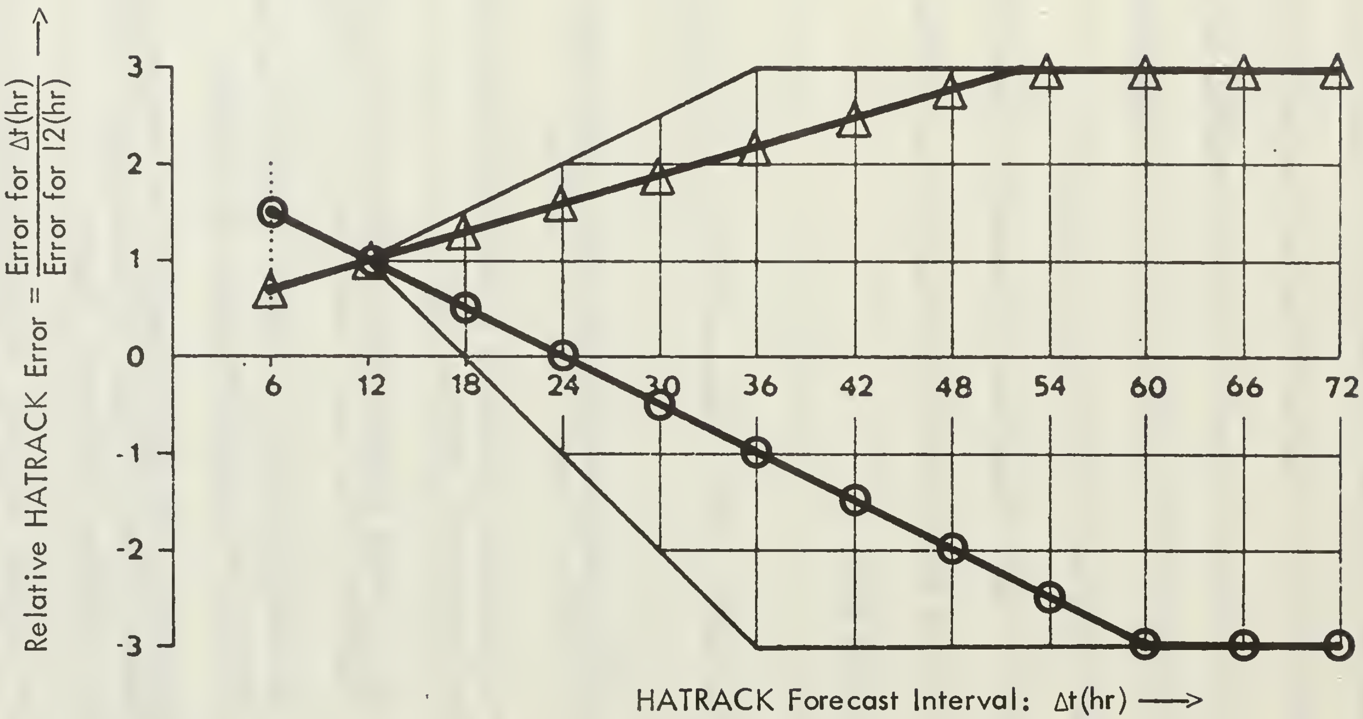

Fig. 1. Diagram for graphically computing the forecast relative HATRACK error as a function of the HATRACK forecast interval. The linear curves illustrate typical latitude (Δ-Δ-Δ) and longitude (0-0-0) forecasts from data in Tables 1 and 2.

TIME	FORECAST INTERVAL (HR)	FORECAST POSITION LAT. (DEG)	LONG. (DEG)	VERIFYING POSITION LAT. (DEG)	LONG. (DEG)	HATRACK ERROR LAT. (DEG)	LONG. (DEG)	RELATIVE HATRACK ERROR LAT.	LONG.
00 GMT Day 1	0			25.0	65.0				
06 GMT Day 1	6	25.1	65.1	25.8	65.4	+0.7	+0.3	+0.7	+1.5
12 GMT Day 1	12	25.5	65.4	26.5	65.6	+1.0	+0.2	+1.0	+1.0

Table 1. Portion of a typical HATRACK forecast set with verifying and error data. See text for details.

TIME	FORECAST INTERVAL (HR)	HATRACK FORECAST POSITION LAT. (DEG)	HATRACK FORECAST POSITION LONG. (DEG)	VERIFYING POSITION LAT. (DEG)	VERIFYING POSITION LONG. (DEG)	FORECAST RELATIVE HATRACK ERROR LAT.	FORECAST RELATIVE HATRACK ERROR LONG.	FORECAST HATRACK ERROR LAT. (DEG)	FORECAST HATRACK ERROR LONG. (DEG)	MODIFIED HATRACK FORECAST POSITION LAT. (DEG)	MODIFIED HATRACK FORECAST POSITION LONG. (DEG)	REGENERATED FORECAST INTERVAL (HR)
00 GMT Day 1	0			25.0	65.0							
06 GMT Day 2	6	25.1	65.1	25.8	65.4	+0.7	+1.5	+0.7	+0.3			
12 GMT Day 1	12	25.5	65.4	26.5	65.6	+1.0	+1.0	+1.0	+0.2			
18 GMT Day 1	18	25.9	65.6			+1.3	+0.5	+1.3	+0.1	27.2	65.7	6
00 GMT Day 2	24	26.0	65.9			+1.6	0.0	+1.6	0.0	27.6	65.9	12
00 GMT Day 3	48	27.8	67.4			+2.8	-2.0	+2.8	-0.4	30.6	67.0	36
06 GMT Day 3	54	28.2	67.6			+3.0	-2.5	+3.0	-0.5	31.2	67.1	42
12 GMT Day 3	60	28.5	67.9			+3.0	-3.0	+3.0	-0.6	31.5	67.3	48
00 GMT Day 4	72	29.4	68.5			+3.0	-3.0	+3.0	-0.6	32.4	67.9	60

Table 2. Portion of typical HATRACK forecast set with verifying and error data through 12 hours and derived MODIFIED HATRACK forecast data for selected intervals from 18 to 72 hr. See text for details.

FORECAST INTERVAL (HRS)	NUMBER OF FORE-CASTS	Latitude		Longitude		Total	
		HATRACK	OFF/HATR	HATRACK	OFF/HATR	HATRACK	OFF/HATR
			Non-Homogeneous Sample				
7-18	N: 231 O: 213	4.6	1.06	4.4	1.43	7.1	1.01
19-30	N: 219 O: 209	3.9	.92	3.9	1.21	6.2	1.05
31-42	N: 207 O: ---	3.8		3.8		6.1	
43-54	N: 170 O: 186	3.6	.95	3.7	1.14	5.8	1.03
55-72	N: 190 O: 156	3.1	1.13	3.7	1.27	5.3	1.21
Average Error Ratio:			1.02		1.27		1.07
			Homogeneous Sample				
8	59	5.3	.91	5.3	1.00	8.3	.93
20	55	4.4	.84	4.0	1.08	6.7	.93
44	42	4.0	.85	3.7	1.08	6.2	.95
68	20	3.3	.91	3.5	1.35	5.2	1.18
Average Error Ratio:			.87		1.08		.96

Table 3. Verification statistics for 1967 operational SR 700 mb Anal- and Prog-mode HATRACK forecasts for the North Atlantic Ocean, with comparisons to official forecast errors (kt).

FORECAST INTERVAL (HRS)	NUMBER OF FORE-CASTS	Latitude		Longitude		Total	
		HATRACK	OFF/HATR	HATRACK	OFF/HATR	HATRACK	OFF/HATR
			Non-Homogeneous Sample				
7-18	N: 186 O: 106	5.4	.83	4.1	1.37	7.5	1.09
19-30	N: 177 O: 100	4.5	.73	3.9	.97	6.5	.88
31-42	N: 162 O: ---	4.0		4.1		6.2	
43-54	N: 148 O: 78	3.4	.88	3.9	1.10	5.6	1.04
55-72	N: 147 O: 51	2.6	.92	3.8	1.00	4.9	1.04
Average Error Ratio:			.83		1.12		1.01
			Homogeneous Sample				
O: 8 N: 12	61	5.4	.91	4.4	1.27	7.7	1.09
O: 20 N: 24	57	4.5	.73	3.9	1.02	6.6	.88
O: 44 N: 48	42	3.5	.80	3.6	1.05	5.4	.97
O: 68 N: 72	9	1.7	.88	2.7	1.49	3.5	1.28
Average Error Ratio			.82		1.14		1.00

Table 4. Verification statistics for 1968 operational SR 700 mb Anal- and Prog-mode HATRACK forecasts for the North Atlantic Ocean, with comparisons to official forecast errors (kt).

	NUMBER OF FORECASTS (PERCENT)	
	1967	1968
AREA		
A (≈ east of 62W)	52	39
B (≈ west of 62W; south of 30N)	31	31
C (≈ west of 62W; north of 30N)	17	30
TRACK		
Before recurvature	66	14
After recurvature	34	86
STAGE		
Depression	10	21
Storm	24	49
Hurricane	64	30
Extra tropical	2	0
Total Number of HATRACK Forecasts	1,017	820

Table 5. Stratification of the 1967 and 1968 operational SR 700 mb Anal- and Prog-mode HATRACK forecasts for the North Atlantic Ocean.

FORECAST INTERVAL	NUMBER OF FORE-CASTS	Latitude		Longitude		Total	
		MOD HATR	OFF/MOD	MOD HATR	OFF/MOD	MOD HATR	OFF/MOD
1967							
O: 8 N: 12	83	2.2	2.15	2.2	2.64	3.4	2.45
O: 20 N: 24	81	2.6	1.40	2.8	1.70	4.2	1.57
O: 44 N: 48	56	2.7	1.10	3.3	1.23	4.8	1.17
Average Error Ratio:			1.61		1.94		1.80
1968							
O: 8 N: 12	65	2.0	2.40	2.6	2.35	3.5	2.43
O: 20 N: 24	61	2.6	1.34	3.2	1.16	4.5	1.27
O: 44 N: 48	47	2.7	1.09	3.7	.96	5.0	1.05
Average Error Ratio:			1.67		1.55		1.65

Table 6. Homogeneous sample of SR 700 mb Anal- and Prog-mode MODIFIED HATRACK and Official forecast errors (kt).

FORECAST INTERVAL (HR)	NUMBER OF FORECASTS	Total Error MOD HATR	NHC-67	NHC/MOD
		ATLANTIC 1967		
12	39	3.7	6.1	1.65
24	39	4.2	4.6	1.10
36	33	4.8	5.6	1.17
48	33	5.3	6.3	1.19
Average Error Ratio:				1.29
		ATLANTIC 1968		
12	17	4.0	5.1	1.28
24	17	4.5	4.7	1.04
36	17	4.6	4.7	1.03
48	16	4.4	5.9	1.33
Average Error Ratio:				1.17

Table 7. Homogeneous sample of SR 700 mb Anal- and Prog-mode MODIFIED HATRACK and NHC-67 forecast errors (kt).

PACIFIC

FORECAST INTERVAL GROUP (HR)	NO. OF FORECASTS	Latitude		Longitude		Total	
		MOD HATR	HATR/MOD	MOD HATR	HATR/MOD	MOD HATR	HATR/MOD
7-18	296	2.3	1.43	2.7	1.94	4.0	1.72
19-30	254	2.9	1.11	3.1	1.40	4.7	1.26
31-42	168	3.3	1.06	3.4	1.09	5.2	1.06
43-54	116	3.6	1.04	3.4	.93	5.4	1.00
Average Error Ratio:			1.20		1.46		1.35

Table 8. Homogeneous sample of 1967 Prog-mode HATRACK and MODIFIED HATRACK forecast errors (kt) (Latitude: SR 500 mb; longitude: SR 700 mb).

PACIFIC

FORECAST INTERVAL (HR)	NO. OF FORECASTS	Latitude		Longitude		Total	
		MOD HATR	OFF/MOD	MOD HATR	OFF/MOD	MOD HATR	OFF/MOD
24	149	2.6	1.21	3.1	1.17	4.6	1.19
48	89	3.2	1.08	3.6	1.24	5.4	1.19
Average Error Ratio:			1.16		1.20		1.19

Table 9. Homogeneous sample of 1967 Prog-mode MODIFIED HATRACK and Official forecast errors (kt) (Latitude: SR 500 mb; longitude: SR 700 mb).

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ABSTRACT

The Navy's numerical-statistical scheme for forecasting the motion of tropical cyclones is reviewed. The numerical component (HATRACK) represents geostrophic steering of the cyclone by the Fleet Numerical Weather Central's smoothed isobaric height fields at 1000, 700, and 500 mb. The statistical component refers to the correction for bias in the numerical steering. The paper introduces an improvement in application of the statistical correction for bias. The enhanced scheme, MODIFIED HATRACK, is applied to forecasts of all named North Atlantic tropical cyclones in 1967 and 1968 and to a select number of 1967 North Pacific tropical storms and typhoons. The accuracy of MODIFIED HATRACK is found to excel the official forecast and that of the National Hurricane Center's NHC-67 technique for all forecast intervals through 48 hours. MODIFIED HATRACK errors range from an average of 40 nautical miles at 12 hours to 240 nautical miles at 48 hours. Such figures represent a 60 percent and a 10 percent reduction in errors, respectively, compared to official forecasts in the Atlantic. For the Pacific, the error reductions are of the order of 15 percent.

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